

NACA

REPORT No. 2.

PART 2.

THE THEORY OF THE PITOT AND VENTURI TUBES.

By E. BUCKINGHAM.

1. THE ENERGY EQUATION FOR STEADY ADIABATIC FLOW OF A FLUID.

Let a fluid be flowing steadily along a channel with impervious and nonconducting walls, from a section A to a section A_1 , the areas of the sections perpendicular to the direction of flow being also denoted by A and A_1 . By saying that the flow is "steady" we do not mean that it occurs in stream lines and without turbulence. We mean merely that it is "sensibly" steady; i. e., that such variations of speed, direction of motion, pressure, etc., as may occur at any point in the stream as a result of turbulence are so rapid that our measuring instruments do not respond to them, but indicate only time averages; and that these time averages are constant at any fixed point within the channel. Values of a property of the fluid, or of any other quantity such as speed, "at a point," are therefore to be understood as time averages over a time which is long compared with the speed of variation of the quantity to be measured, though it may appear short in the ordinary sense.

Let θ , p , v , ϵ , T , respectively, be the absolute temperature, static pressure, specific volume, internal energy per unit mass, and kinetic energy per unit mass, at the entrance section A . By the "static pressure" is meant the pressure which would be indicated by a gauge moving with the current. Let θ_1 , p_1 , v_1 , ϵ_1 , T_1 be the corresponding quantities at the exit section A_1 . Both sets of values are to be understood as averages over the whole section, as well as time averages in the sense explained above. The two sections shall be at the same level, so that the passage of fluid from A to A_1 does not involve any gravitational work.

As a unit mass of fluid crosses A , the work pv is done on it by the fluid following; and as it crosses A_1 it does the work p_1v_1 on the fluid ahead. Since the walls of the channel are nonconducting, no heat enters or leaves the fluid between A and A_1 ; hence the total energy, internal plus kinetic, increases (or decreases) by an amount equal to the work done on (or by) the fluid, and we have

$$pv - p_1v_1 = (\epsilon_1 + T_1) - (\epsilon + T) \quad (1)$$

or

$$T - T_1 = (\epsilon_1 + p_1v_1) - (\epsilon + pv)$$

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So far no assumptions have been made and equation (1) is rigorously correct for adiabatic flow between two sections at the same level. Internal heating by skin friction or the dissipation of eddies is merely a conversion of energy from one form into another and not an addition of energy; hence it does not affect the validity of equation (1) and need not appear in it.

2. INTRODUCTION OF THE MEAN SPEED INTO THE ENERGY EQUATION.

Let Q be the volume of fluid which crosses the section A per unit time, and let $S = Q/A$; then S is the arithmetical mean, over the section, of the component velocity normal to A and along the channel. Let Q_1 and S_1 be the corresponding values at A_1 . Measuring kinetic energy, as well as work and internal energy, in normal mass-length-time units, we then set

$$T - T_1 = \frac{1}{2} (S^2 - S_1^2) \quad (2)$$

and proceed to substitute this expression for $(T - T_1)$ in equation (1).

This substitution is indispensable to further progress, but it involves an assumption which destroys the rigor of all further deductions. The deductions are, nevertheless, very approximately confirmed by experiment, and it is therefore worth while to examine the assumption.

If there were no turbulence and if the speed were uniform over each section, we should have the two separate equations

$$T = \frac{1}{2} S^2$$

$$T_1 = \frac{1}{2} S_1^2 \quad (3)$$

and equation (2) would be exact. If there is no turbulence but the speed of flow is nonuniform, approaching zero at the walls, as it must where the channel has material walls, equations (3) will not be satisfied, but we shall have $T > \frac{1}{2} S^2$ and $T_1 > \frac{1}{2} S_1^2$, because the mean square speed, which determines the kinetic energy, is always greater than the arithmetical mean speed S when the distribution over the section is not uniform. With a round pipe and nonturbulent flow $T = \frac{3}{2} S^2$ instead of $\frac{1}{2} S^2$.

In nearly all practical cases the flow of fluids is turbulent and the relation of the whole kinetic energy, including that of the turbulence, to the arithmetical mean normal component of the speed at the given section will depend on the amount of turbulence. It is impossible to say what the relation will be further than that the kinetic energy of eddies and cross currents tends to increase the error which would be involved in assuming equations (3), while, on the other hand, the fact that with increasing turbulence the speed becomes more nearly uniform over a cross section tends to decrease the difference between the mean square and the arithmetical mean of the component normal to any section.

The assumption involved is as violent as that which is made separately. For equation (1) is

whereas equation (2) is

no matter what the velocity, the error is the same at both sections and will occur if the kinetic energy is the same at both sections and if also the error is such that the arithmetical mean square is not evident that the use of the mean-square is nearly fulfilled in practice. Deductions from equation (1) in cases the error is reality quite insignificant.

For geometrically similar cases (2) depends only on $\frac{DS}{v}$, fluid and D a linear dimension of a given channel increase, it is not evident how this error varies at all. Hence, it seems with $\frac{DS}{v}$, the percentage error does not increase but remains the same. On the other hand, at a given speed S and increasing v , the turbulence

and there will be a great error. At a given speed compared to find greater difference deduced from equation (1) than kinematic viscosity than

We shall now proceed by combining it with equation (2)

$$\frac{1}{2} (S^2 - S_1^2) =$$

an equation which serves the Pitot tube, the Venturi tube, and various other devices in which the flow is assumed to be adiabatic.

The assumption involved in using equation (2) is not, however, so violent as that which would be involved in using equations (3) separately. For equations (3) are equivalent to

$$T - \frac{1}{2}S^2 = T_1 - \frac{1}{2}S_1^2 = 0$$

whereas equation (2) is satisfied if

$$T - \frac{1}{2}S^2 = T_1 - \frac{1}{2}S_1^2 \quad (4)$$

no matter what the value is. Equation (4) and its equivalent (2) are satisfied if the error in assuming equations (3) to hold is the same at both sections without vanishing or even being small. This will occur if the kinetic energy of turbulence is the same at both sections and if also the speed distributions over the two sections are such that the arithmetical mean normal speed is the same fraction of the mean-square normal speed at both. While therefore it is evident that the use of equations (3) separately might lead to conclusions at variance with facts, equation (2) may nevertheless be nearly fulfilled in practice. The agreement with observation of deductions from equations (2) and (1) shows that in many ordinary cases the error committed by treating equation (2) as exact is in reality quite insignificant.

For geometrically similar channels, the percentage error of equation (2) depends only on $\frac{DS}{\nu}$, in which ν is the kinematic viscosity of the fluid and D a linear dimension of the channel. With a given fluid in a given channel increasing S increases the turbulence, but it is not evident how this will affect the percentage error, $\frac{2T - S^2}{S^2}$, if at all. Hence, it seems possible that although turbulence increases with $\frac{DS}{\nu}$, the percentage error in assuming equation (2) may not increase but remain constant or even decrease. On the other hand, at a given speed S , if $\frac{DS}{\nu}$ is increased by increasing D or diminishing ν , the turbulence and the value of $\frac{2T - S^2}{S^2}$ will be increased

and there will be a greater chance that equation (2) may be sensibly in error. At a given mean axial speed S we must therefore be prepared to find greater discrepancies between experiment and results deduced from equation (2) for large channels and fluids of low kinematic viscosity than for the opposite conditions.

We shall now proceed as if equation (2) were rigorously exact, and by combining it with equation (1) we obtain

$$\frac{1}{2}(S^2 - S_1^2) = (\epsilon_1 + p_1 v_1) - (\epsilon + p v) \quad (5)$$

an equation which serves as the point of departure for the theory of the Pitot tube, the Venturi meter, the steam-turbine nozzle, and various other devices in which a stream of fluid is retarded or accelerated adiabatically.

3. ISENTROPIC FLOW OF AN IDEAL GAS.

If the physical properties of the fluid have been sufficiently investigated and if a sufficient number of quantities are measured at each of the two sections, the value of $(\epsilon + pv)$ may be computed for each section and the value of $(S^2 - S_1^2)$ found from equation (5), to the degree of approximation permitted by the assumptions which have been discussed above. A process somewhat of this nature is pursued in the design of steam-turbine nozzles, $(\epsilon + pv)$ being then the quantity known as the total heat of steam.

But when the fluid is a gas, it is usual to proceed with deductions from equation (5) by the aid of two further assumptions which enable us to compute variations of ϵ and v from observations of p alone. The first of these assumptions is that the fluid behaves sensibly as an ideal gas defined by the equations

$$pv = R\theta \quad (6)$$

$$\epsilon = \epsilon_0 + C_v (\theta - \theta_0) \quad (7)$$

in which C_v is the specific heat at constant volume, and ϵ_0 is the internal energy at the standard temperature θ_0 . The properties of ordinary gases, such as air, carbon dioxide, or coal gas, when far from condensation, are nearly in conformity with equations (6) and (7), and for such fluids no serious error is involved in making the assumption mentioned, unless very great variations of pressure and temperature are under consideration. Equations (6) and (7) imply also the relation

$$C_p = C_v + R \quad (8)$$

in which C_p is the specific heat at constant pressure.

The second assumption is that during the simultaneous changes of pressure and temperature in passing from A to A_1 the familiar isentropic relation for an ideal gas, viz,

$$\frac{\theta_1}{\theta} = \left(\frac{p_1}{p} \right)^{\frac{k-1}{k}} \quad (9)$$

remains satisfied, k representing C_p/C_v . This assumption is, of course, not exact, for while we have stipulated that the flow shall be adiabatic, the internal heating, due to viscosity causes an increase of entropy. The assumption amounts, therefore, to assuming that this irreversible internal heating is not enough to cause any sensible increase of the temperature at A_1 over what it would be if there were no internal heating at all.

The foregoing assumptions enable us to put equation (5) into a more available form. By substituting from (6) and (7) into (5), and using (8), we have

$$\frac{1}{2} (S^2 - S_1^2) = C_p (\theta_1 - \theta) \quad (10)$$

By means of (9) and (6), this may be written

$$\frac{1}{2} (S^2 - S_1^2) = \frac{C_p}{R} pv \left[\left(\frac{p_1}{p} \right)^{\frac{k-1}{k}} - 1 \right]$$

and by (8) we get C

$$\frac{1}{2} C$$

which is the usual ideal gas. If the s enables us to find t and an observation (11) gives us similar A_1 if the density an equation to both the

4. TH

To treat the Pitot the dynamic opening presence of the Pitot particle of fluid app mixes with the per fluid, which covers the differential gauge or another indistingu being accelerated by along the impact tul when it has reached wish to apply equatio way of doing so.

Starting with the co current and perpendi imagination, a tubula parallel to the mean c as found by averagin turbulent, this tube i through its sides. If in practice, the same f as it would if the wall of fluid are continuall bulent time-changes c and these particles ar total mass, which ente the particles which en along the tube as tho could, merely by imag fluid a particular filan or slower than the su effect of turbulence is made rigid and perfec exerting any skin fricti

If the whole current across its general dire tubular surface, and ec an impervious noncon if the tube is of small s

and by (8) we get $C_p/R = \frac{k}{k-1}$ so that we have

$$\frac{1}{2} (S^2 - S_1^2) = \frac{k}{k-1} p v \left[\left(\frac{p_1}{p} \right)^{\frac{k-1}{k}} - 1 \right] \quad (11)$$

which is the usual form of equation (5) for isentropic flow of an ideal gas. If the speed is known at either section, equation (10) enables us to find the speed at the other from a knowledge of C_p and an observation of the difference of temperature; while equation (11) gives us similar information in terms of the pressures at A and A_1 if the density and the ratio k are known. We shall apply this equation to both the Pitot tube and the Venturi meter.

4. THE THEORY OF THE PITOT TUBE.

To treat the Pitot tube, we consider the fluid which is approaching the dynamic opening. Starting at a point so far upstream that the presence of the Pitot tube produces no sensible disturbance there, a particle of fluid approaches the dynamic opening, slows down, and mixes with the permanent high-pressure cap of nearly stationary fluid, which covers the dynamic opening and communicates with the differential gauge through the impact tube. The same particle, or another indistinguishable from it, emerges from the cap and, being accelerated by the now positive pressure gradient, flows on along the impact tube, finally acquiring a sensibly constant speed when it has reached a region of sensibly constant pressure. We wish to apply equation (5) to this motion if we can find a plausible way of doing so.

Starting with the contour of a small plane area, in the undisturbed current and perpendicular to its general direction, we construct, in imagination, a tubular surface of which the sides are at every point parallel to the mean direction of motion of the fluid past that point, as found by averaging with regard to time. If the motion is not turbulent, this tube is a tube of flow and no fluid passes in or out through its sides. If the motion is turbulent, as it nearly always is in practice, the *same* fluid does not flow continuously along the tube as it would if the walls were impervious. On the contrary, particles of fluid are continually leaving the tube in consequence of the turbulent time-changes of the direction of motion at any fixed point; and these particles are continually replaced by others, of the same total mass, which enter from without the tube. But on the whole, the particles which enter have the same average component velocity along the tube as those which leave; for unless this were true we could, merely by *imagining* the tubular surface, generate within the fluid a particular filament which was moving, on the whole, faster or slower than the surrounding fluid. We conclude that the net effect of turbulence is the same as if the imaginary tube walls were made rigid and perfectly reflecting for mechanical impact without exerting any skin friction on the fluid flowing along them.

If the whole current of fluid is at a sensibly uniform temperature across its general direction, no heat passes in or out through the tubular surface, and equation (5) may be applied as though we had an impervious nonconducting channel to deal with. Furthermore, if the tube is of small section, the axial speed, averaged with regard

to time, will be the same at all points of any one cross section. Hence the application of equation (5), involving the assumption of equation (2) or (4), is better justified than for a material tube in which skin friction would cause the axial speed to be nonuniform over any section.

We now consider such an imaginary tube, starting in the undisturbed fluid some distance upstream from the dynamic opening of the Pitot tube, passing into the high-pressure cap over the opening and emerging again at the edge of the opening, to continue its course along the side of the impact tube. The portion of the imaginary tube which passes through the high-pressure cap may be regarded as an enlargement of cross section at which the mean axial speed is so reduced that its square is negligible in comparison with the square of the speed at distant points. If we let A be a section at some distance upstream and A_1 be the section of the tube where it passes through the high-pressure cap, S_1^2 is negligible in comparison with S^2 and equation (5) gives us

$$S = \sqrt{2[(\epsilon_1 + p_1 v_1) - (\epsilon + pv)]} \quad (12)$$

in which S is the speed of the undisturbed current; ϵ , p , and v refer to conditions in the undisturbed current; and ϵ_1 , p_1 , v_1 refer to conditions in the dynamic opening. The static pressure, which the static opening is designed to receive and transmit to the gauge, is p ; while the pressure received by the dynamic opening is that in the permanent high-pressure cap, or p_1 .

Equation (12) is the general form of the Pitot tube equation for any fluid, whether compressible or not. In the case of a liquid, the internal energy and specific volume are not appreciably affected by the very small pressure variations involved, so that we have $\epsilon_1 = \epsilon$ and $v_1 = v$ and equation (12) reduces to

$$S = \sqrt{2v(p_1 - p)} = \sqrt{2 \frac{p_1 - p}{\rho}} \quad (13)$$

ρ being the density of the liquid. If the pressure difference is expressed as a head h of liquid of density d , we have $p_1 - p = gh d$ and equation (13) takes the form

$$S = \sqrt{2g \frac{d}{\rho} h} \quad (14)$$

the usual form of the Pitot tube equation for a perfect or ideal tube.

Even when the fluid is a gas, if S is small and $(p_1 - p)$ therefore also small, ϵ_1 and v_1 are nearly the same as ϵ and v so that equations (13) and (14) remain approximately correct—admitting all the assumptions made—though it is not evident how close the approximation will be. But if the speed and the pressure difference are great enough to cause sensible compression, we must return to equation (5) and introduce the conditions for adiabatic flow of a gas, as was done in section 3 in arriving at equation (11). The fact that equation (14) does agree well with observations on gas currents at moderate speeds, shows that no great error is involved in neglecting compressibility

and justifies us in going the gas as ideal and compressibility.

Assuming, then, the current tube now under equation

S

If we now set $\frac{p_1}{p} = 1 + \lambda$

$$\left(\frac{p_1}{p}\right)^{\frac{k-1}{k}} - 1 = n$$

Setting the $\{ \dots \} = \lambda$

$$\text{that } n \Delta = \frac{k-1}{k} \frac{p_1 - p}{p}$$

which differs from compressibility, only in the

$$X = \left\{ 1 + \frac{n-1}{2} \Delta + \frac{(n-1)}{1} \right\}$$

The quantity $\Delta = \frac{p_1 - p}{p}$ is the ratio of the pressure difference to the static pressure. The value that $n = \frac{k-1}{k}$ is always

X containing Δ are all small the series converges nearly equal to the first sum is negligible and

The ratio of the speed to the speed of sound have

$$X = \left\{ 1 \right\}$$

If an error of y per cent also be allowed in the values of the error y found from equation

and justifies us in going on to find a closer approximation by treating the gas as ideal and thereby using an approximation to the compressibility.

Assuming, then, that equation (11) is applicable to the imaginary current tube now under discussion, we have, by setting $S_1^2 = 0$, the equation

$$S = \sqrt{\frac{2k}{k-1} \frac{p}{\rho} \left[\left(\frac{p_1}{p} \right)^{\frac{k-1}{k}} - 1 \right]} \quad (15)$$

If we now set $\frac{p_1}{p} = 1 + \Delta$ and $\frac{k-1}{k} = n$ we have

$$\left(\frac{p_1}{p} \right)^{\frac{k-1}{k}} - 1 = n\Delta \left\{ 1 + \frac{n-1}{2} \Delta + \frac{(n-1)(n-2)}{1 \cdot 2 \cdot 3} \Delta^2 + \text{etc.} \right\}$$

Setting the $\{ \dots \} = X^2$, substituting in equation (15), and noticing

that $n\Delta = \frac{k-1}{k} \frac{p_1 - p}{p}$ we have

$$S = X \sqrt{2 \frac{p_1 - p}{\rho}} \quad (16)$$

which differs from equation (13), obtained by disregarding compressibility, only in the correction factor

$$X = \left\{ 1 + \frac{n-1}{2} \Delta + \frac{(n-1)(n-2)}{1 \cdot 2 \cdot 3} \Delta^2 + \frac{(n-1)(n-2)(n-3)}{1 \cdot 2 \cdot 3 \cdot 4} \Delta^3 + \dots \right\}^{\frac{1}{2}} \quad (17)$$

The quantity $\Delta = \frac{p_1 - p}{p}$ is the fractional rise of pressure at the mouth of the impact tube: hence it is, in practice, always a small quantity. The value of k for gases is always between $\frac{5}{3}$ and 1, so that $n = \frac{k-1}{k}$ is always between $\frac{2}{3}$ and 0. Accordingly the terms of X containing Δ are alternately negative and positive and when Δ is small the series converges rapidly, the sum of all the terms in Δ being nearly equal to the first term alone, so that if the first is negligible the sum is negligible and X may be set equal to unity.

The ratio of the specific heats of air is 1.40. Hence $n = \frac{2}{7}$ and we have

$$X = \left\{ 1 - \frac{5}{14} \Delta + \frac{10}{49} \Delta^2 - \frac{95}{686} \Delta^3 + \text{etc.} \right\}^{\frac{1}{2}} \quad (18)$$

If an error of y per cent. in S is permissible, an error of y per cent. may also be allowed in the correction factor X and the value of Δ may be, at most, such as to make $\frac{5}{28} \Delta = \frac{y}{100}$ or $\Delta = 0.056y$. For any assigned values of the error y per cent. in the speed, the value of S can be found from equation (13).

Let us suppose, for example, that the Pitot tube is to be used for measuring the speed of an aeroplane and that an accuracy of 0.5 per cent. is sufficient. Then we have $\Delta = 0.028$ and $p_1 - p = 0.028 p$. To find what speed would give this head on the differential gauge, we set $p = 1$ atmosphere $= 1.013 \times 10^6$ dynes/cm.² and $\rho = 0.0013$ gram/cm.³ and substitute in (13), the result being $S = 66.1$ m./sec. $= 212$ ft./sec. $= 148$ miles/hour. Since an accuracy of better than 1.0 per cent. can hardly be demanded of an aeroplane speedometer, it is evident that for all ordinary speeds of flight, no correction for compressibility is needed and equations (13) and (14) may be used.

It is of course a simple matter to compute values of the correction factor X for various speeds; but in view of the uncertainties and assumptions involved in the theory, the results would have a misleading appearance of accuracy and would not in fact be worth the labor of computation. What has been shown is sufficient, namely, that if a Pitot tube does not measure the speed of an aeroplane correctly the error is not due to neglecting the compressibility of the air.

5. THE THEORY OF THE VENTURI METER.

The Venturi meter is a channel of varying cross section, and we may apply to it the general equations of flow which have already been developed. In doing so, we shall let A be the entrance section of the meter where p is measured, and A_1 be the throat section at which the diminished pressure p_1 is observed. We have to use equation (5).

If the meter is used for measuring the flow of a liquid of density ρ we may set $\epsilon_1 = \epsilon$ and $v_1 = v$ as we did in treating the Pitot tube, and equation (5) then gives us

$$S_1^2 - S^2 = 2 \frac{p - p_1}{\rho} \quad (19)$$

Neither S nor S_1 vanishes; but in addition to (19) we have the equation of continuity which for a fluid of constant density may be written

$$S_1 A_1 = S A \quad (20)$$

and (19) and (20) together enable us to find either S or S_1 . If we represent the area ratio by a single symbol

$$\frac{A}{A_1} = \alpha > 1 \quad (21)$$

we have

$$S = B \sqrt{2 \frac{p - p_1}{\rho}} \quad (22)$$

where

$$B = \sqrt{\frac{1}{\alpha^2 - 1}} \quad (23)$$

and B is a constant characteristic of the given meter.

Comparing (22) with (13), the equation for the Pitot tube in a liquid, we see that they differ only by the factor B which depends on

the area ratio α . If α difference $(p - p_1)$ will tube with its dynamic

various values of the r we have the following

$$\begin{aligned} \frac{D}{D_1} &= 1.5 \\ \alpha &= 2.25 \\ B &= 1.569 \end{aligned}$$

Evidently, the Venturi larger than the Pitot the gauge reading be r

If the fluid is a gas negligible at sufficient tion (22) may be used allowed for. To treat assumptions as in sec and that the flow fro sensibly isentropic, th from the walls of the being insignificant. V case in hand, and if by a single symbol an

we have by equation (

$$S_1^2 -$$

ρ being the density entrance section.

To combine with (2

and if we remember th of an ideal gas pv^k may be written

By using (26) to elim

$$S =$$

by means of which th observed pressure ra properties of the gas

the area ratio α . If $\alpha = \sqrt{2}$, $B = 1$ and the observed Venturi pressure difference $(p - p_1)$ will be the same as would be shown by a Pitot tube with its dynamic opening in the entrance of the meter. For various values of the ratio $\frac{D}{D_1}$ of entrance diameter to throat diameter we have the following values of B :

$\frac{D}{D_1} =$	1.5	2.0	2.5	3.0	4.0
$\alpha =$	2.25	4.00	6.25	9.00	16.00
$B =$	1.569	3.874	6.170	8.944	15.77

Evidently, the Venturi pressure difference may easily be made much larger than the Pitot pressure difference at the entrance speed and the gauge reading be made much more sensitive.

If the fluid is a gas instead of a liquid, compressibility will still be negligible at sufficiently low speeds, as for the Pitot tube, and equation (22) may be used; but in general the compressibility must be allowed for. To treat the flow of a gas, we have to make the same assumptions as in section 3, namely, that the gas is sensibly ideal and that the flow from the entrance section A to the throat A_1 is sensibly isentropic, the combined effect of heat conduction to or from the walls of the meter, and of internal heating in the gas itself, being insignificant. We then have to apply equation (11) to the case in hand, and if for simplicity we represent the pressure ratio by a single symbol and write

$$\frac{p_1}{p} = r < 1 \quad (24)$$

we have by equation (11)

$$S_1^2 - S^2 = \frac{2k}{k-1} \frac{p}{\rho} \left[1 - r^{\frac{k-1}{k}} \right] \quad (25)$$

ρ being the density of the gas at the pressure p as it crosses the entrance section.

To combine with (25) we have the equation of continuity

$$S_1 A_1 \rho_1 = S A \rho$$

and if we remember that during isentropic compression or expansion of an ideal gas pv^k remains constant, the equation of continuity may be written

$$S_1 = \frac{\alpha}{r^{1/k}} S \quad (26)$$

By using (26) to eliminate S_1 from (25) we now obtain the equation

$$S = \left\{ \frac{2k}{k-1} \frac{r^{2/k}}{\alpha^2 - r^{2/k}} \frac{p}{\rho} \left(1 - r^{\frac{k-1}{k}} \right) \right\}^{1/2} \quad (27)$$

by means of which the entrance speed S may be computed from the observed pressure ratio $r = p_1/p$ when the area ratio α and the properties of the gas are known. Since we are treating the gas as

ideal, p/ρ is, for any given gas, proportional to the absolute temperature θ at the entrance section, and we may write $\frac{p}{\rho} = \frac{p_o}{\rho_o} \frac{\theta}{\theta_o}$, ρ_o being the density of the gas at the standard pressure p_o and temperature θ_o .

For air, $\frac{C_p}{C_v} = k = 1.40$ and if we insert the known value of ρ_o at 1 atmosphere and 0°C . and set

$$S = Y \sqrt{\frac{\theta}{\theta_o}} \quad (28)$$

where

$$Y = \left\{ \frac{2k}{k-1} \cdot \frac{r^{2/k}}{\alpha^2 - r^{2/k}} \left(1 - r^{\frac{k-1}{k}} \right) \frac{p_o}{\rho_o} \right\}^{1/2}$$

we have the values of Y shown in the following table for various pressure ratios r and for meters in which the throat diameter is $\frac{1}{2}$, $\frac{1}{3}$, or $\frac{1}{4}$ of the entrance diameter, i. e., $\alpha = 4, 9$, or 16 . If t is the temperature at entrance, on the centigrade scale $\frac{\theta}{\theta_o} = \frac{273+t}{273}$ while if t is measured on the Fahrenheit scale,

$$\frac{\theta}{\theta_o} = \frac{460+t}{492}$$

THE VENTURI METER FOR AIR.

Values of Y in $S = Y \sqrt{\frac{\theta}{\theta_o}}$

S = Speed at entrance to meter $\alpha = \frac{A}{A_1} = \frac{\text{entrance area}}{\text{throat area}}$

r = throat pressure \div entrance pressure $= p_1/p$ θ = absolute temperature of air at entrance.

θ_o = absolute temperature of ice point.

Values of Y .

r	$\alpha = 4$			$\alpha = 9$			$\alpha = 16$		
	M./sec.	Ft./sec.	Mile/hour.	M./sec.	Ft./sec.	Mile/hour.	M./sec.	Ft./sec.	Mile/hr.
0.9998	1.44	4.74	3.23	0.626	2.05	1.400	0.350	1.150	0.784
.999	3.23	10.60	7.23	1.40	4.59	3.13	0.784	2.57	1.753
.995	7.21	23.65	16.13	3.12	10.24	6.98	1.75	5.74	3.91
.99	10.16	33.34	22.7	4.40	14.11	9.85	2.47	8.09	5.52
.98	14.3	46.48	32.0	6.19	20.3	13.85	3.47	11.38	7.76
.95	22.2	72.8	49.6	9.62	31.6	21.5	5.39	17.7	12.06
.90	30.4	99.8	68.0	13.2	43.4	29.6	7.41	24.3	16.57
.80	40.2	131.7	89.8	17.5	57.5	39.2	9.82	32.2	22.0
.60	48.1	157.9	107.6	21.1	69.3	47.2	11.86	38.9	26.5

Computed on the assumptions $pv = R\theta$, $C_v = \text{constant}$, $\frac{C_p}{C_v} = 1.400$.

$p_o = 1.01323 \times 10^6 \text{ dyne/cm}^2$.

$\rho_o = 0.0012928 \text{ gm cm}^3 \text{ at } 760 \text{ mm. and } 0^\circ \text{C}$

REPORT ON IN AND CAB TE

By JOH